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# The social processes of production and validation of knowledge in particle physics: Preliminary theoretical and methodological observations

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## Abstract

This paper explores the complementarities and differences between Bourdieu's Field Theory and Social Network Analysis from both a theoretical and methodological perspective. The argument is applied to a case study about the social production and validation of knowledge in particle physics in Italy. The methodological choices that have lead the research project are presented and justified, and provide a good example about the strengths and the weaknesses of the two theoretical perspectives combined. While the Field Theory approach allows mapping the combination and distribution of symbolic capital within a social structure of objective relationships, SNA is useful to analyze the concrete set of interactions within physicists, in which the dynamics of power, alliances, conflicts and exchange take place. Data have been collected using a mixed method strategy, which entails desk research, on line questionnaires and qualitative interviews. Some potential strategies for analyzing the data are presented in the discussion section.

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**Keywords:** Sociology of science; Bourdieu; field theory; social network analysis; mixed methods

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## 1. Introduction

The production of knowledge has always been a key factor in society and some contemporary scholars advance the argument that its production and accessibility play a critical role in today's western societies. It is argued that societies are now knowledge-based (OECD 1999a; OECD 1999b) and that knowledge is the main stay of social inclusion (Castells 1996). Understanding how knowledge is produced and validated entails some sociological questions regarding the structure of power, hierarchies, controversies, and alliances which underlie the work of science itself.

This paper addresses some of these questions, presenting the theoretical background and the methodological choices of a research project on the production of knowledge in particle physics in Italy. The two year Project of Relevant National Interest (PRIN) ended in 2008, and was funded by the Italian Ministry of University and Research (MIUR) and directed by Paolo Volontè at University of Bolzano. The main goal of the research was to

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explore the social organization of the field of particle physics in Italy in order to elicit some structural features that promote or hinder the production and validation of scientific knowledge. We gathered data on the social and structural aspects of the scientists' community and on their scientific productivity. While we did manage to collect a wide quantity of data on the physicists' structural positions and social backgrounds and trajectories, the collection of information about scientific production has been limited by time, accessibility and funding, and still needs further investigation. Since the data have been only partially analyzed, we concentrate on theoretical and methodological issues.

The first section reviews some of the main theoretical approaches in sociology of science, outlining the terms of the debates and reviewing some of the studies that made use of Social Network Analysis. It also summarizes Bourdieu's criticisms of other approaches. In the second section we present Bourdieu's Field Theory as the main framework of this research and justify the selection of this approach. We also highlight some similarities and differences between Field Theory and Social Network Analysis. The third section presents some contextual background of particle physics in Italy, as well as the empirical definition of the field. This has helped us to define the population and to make methodological choices. Some of these choices have had to be compromised with regard to the ideal strategy for data collection and have exposed some weaknesses of Bourdieu's approach in terms of the effective possibilities of empirical exploration of the theoretical concept of fields. The fourth section presents some data from which we identified social networks that have been used to represent and analyze the structure of the field of physics. SNA data have been collected via a mixed methods strategy, where information is obtained through the collection of secondary sources, a web survey and qualitative interviews and combined together to resolve the lack of data completeness inherent in each method. In the discussion, we address some of the raised issues in mixing methods for the empirical investigation of Bourdieu's field approach, showing the importance of SNA techniques and qualitative approaches to increase the potential and overcome some of the limits of his theoretical framework. The conclusions point out the work that still need to be done, as well as weaknesses of this research project.

## **2. The sociology of science: unpacking the black box of knowledge production**

The production of knowledge is the main object of analysis in the sociology of science. Various sociological approaches have tried to uncover the social factors that play a crucial role in scientific discoveries and validation of results, creating a scholar tradition in the study of sociology of science that has been uncovered several social aspects of the work of scientists.

Some of the earlier scholars studying science productions were more interested in finding the cultural values and mores that regulate the scientific activities (Merton 1968). rather than explaining the procedures for the validation of knowledge. However, much of the subsequent work has tried to open the "black box" of the construction of the contents of science, and the attention has shifted to analyze controversies and conflicts that lead to changes in scientific paradigms (Kuhn 1962). The merit of linking the production and validation of scientific products to local socio-cultural norms belongs to the Edinburgh School and the work of Barnes and Bloor (1982). as well as to Collins (1985) and the Bath school, who are interested in the processes of interactions in and through which interests, preferences and beliefs are formed. Finally, laboratory studies (Knorr-Cetina 1992) push further the concept of scientific objects as social and cultural constructions, showing how they are technically built in laboratories and symbolically made up through literary and political discourses, whose goal is making alliances and gaining resources.

A very interesting departure from previous approaches in sociology of science can be found in the actor-network theory (ANT) developed by Latour and Callon (see for example Latour 1987 and 2005). Here the concept of network is introduced, where actors can be equally people, objects and organizations. The main problem of such approach lies in the fact that ANT theory tends to be highly deterministic in terms of network constraints over actors: once an actor network is stabilized, the possibilities of actions become increasingly narrow (Whittle and Spicer 2008). There seems no space for actors' reflexivity and resistance, and the structure of power seems to be fully determined.

A different conceptualization of network has been used by the structural perspective, which conducts a structural analysis of citations between articles: here peer-recognized prestige does not only depend on number of citations, as in bibliometric approaches (Garfield 1979). but also on centrality of cited articles (Noma 1982) and paths of citations (Hummon and Doreian 1989). Social Network Analysis has developed many studies that make use of path

analysis (Carley 1993; Harris, Luke, Zuckerman and Shelto 2009); it has proposed methods where path analysis and bibliometry (Calero-Medina and Noyons 2008) or co-authorship and citations (Lambiotte and Panzarasa 2009) are combined. It has implemented centrality measures and path analysis using other network measures, like longitudinal analysis of components and their properties (Tomassini and Luthi 2007) and preferential attachment law (Tomassini and Luthi 2007; Wang, Yu and Yu 2009). Moreover, other network scholars have explored the possibility of using several sources of data in order to map different kind of relationships, searching for the informal structures that lead to invisible colleges or scientific communities (Lieberman and Wolf 1997 and 1998; Lievrouw, Rogers, Lowe and Nadel 1987).

Bourdieu criticises these theoretical positions for several reasons: while Merton's approach leads to a weak sociology of science that does not face the importance of social interaction and conflicts in the process of knowledge validation, subsequent scholars have failed to link the cultural and technical aspects of scientific production to the wider social structure. They are limited, according to Bourdieu's point of view, to the analysis of internal controversies and revolutions (Kuhn), to the interactionist perspective (the Edinburgh and Bath School), and to the narrow context of laboratory studies and the analysis of laboratory notes, where the production of knowledge seems to depend upon individual strategies and political tactics (Bourdieu 2004a).

Regarding the SNA approach, Bourdieu claims that it does not uncover "the structure of distribution of species of capital which tends to determinate the structure of individual or collective stances taken, through the interests and dispositions it conditions. In network analysis, the study of these underlying structures has been sacrificed to the analysis of particular linkages (between agents and institutions) and flows (of information, resources, services, etc.) through which they become visible" (Bourdieu 2004b: 114). While it is true that SNA investigations on the production of knowledge do not seem to take into account simultaneously all the factors that contribute to the construction and accumulation of symbolic capital (as they do not provide extensive information on economic, cultural, social capital and social trajectories of scientists), Bourdieu seems to be unaware of some SNA work that explores, for example, the influence of media together with personal networks on adoption of innovations (Lazarsfeld, Berelson and Gaudet 1944; Katz and Lazarsfeld 1955; Berelson, Lazarsfeld and McPhee 1954, Michaelson 1993). Furthermore, Bourdieu's theoretical standing implies so many difficulties in data collection that it is practically unlikely that the whole system of Field Theory can be translated in research indicators and therefore seems to be empirically unusable.

### 3. Bourdieu's Field Theory and Social Network Analysis

In contrast to some of the other frameworks in sociology of science, Bourdieu's Field Theory devotes much of attention to the structural possibilities and constraints that shape scientific production. The field of science is, in Bourdieu's view, a social field of strengths with its own structure and battles to conserve or change the hierarchical structure that is produced by the field itself. Scientists build up the field through their relationships, which means that the field structure is generated by actors' relationships. The possibility, for every actor to deform the field depends on his/her weight, which consist in the relative amount of symbolic capital which everyone owns. The symbolic capital is "the form that one or another of capital species [economic, cultural and social capital] takes when it is grasped through categories of perception that recognize its specific logic or, if you prefer, misrecognize the arbitrariness of its possession and accumulation" (Bourdieu 2004b: 119). This symbolic capital assumes a special feature in the scientific field and it is called scientific capital, made by *connaissance* and *reconnaissance* (Bourdieu 2004a). Victory is measured in terms of the amount of scientific capital attributed to each scientist (and the institutions to which he or she belongs) by his or her peers. Therefore the stake is internal to the field and grants its autonomy from other social spheres.

Bourdieu (2004b: 104-105) gives precise methodological indications for the exploration of a social field. First of all, researchers have to locate the field under investigation (in this case, the field of science) in relation to other dominant fields. Then they have to "map out the objective structure of relations between the positions occupied by the agents or institutions who compete for the legitimate form of specific authority of which this field in the site" (Bourdieu 2004b: 105). Positions are defined by the composition of the capitals that are required to gain them. This composition can vary according to what powerful agents decide is valuable within the field, and it shapes distinctions between actors. Finally, they have to "analyse the habitus of agents, the different system of dispositions

they have acquired by internalizing a determinate type of social and economical conditions” (Bourdieu 2004b: 105). We can now analyse some similarities between Field Theory and SNA approach. Bourdieu himself says that:

In analytic terms, a field may be defined as a network, or a configuration, of objective relations between positions. These positions are objectively defined, in their existence and the determinations they impose upon their occupants, agents or institutions, by their present and potential situation (*situs*) in the structure of the distribution of species of power (or capital) whose possession commands access to the specific profits that are at stake in the field, as well as by their objective relation to other positions (domination, subordination, homology, etc.) (Bourdieu 2004b: 97).

Such a definition closely resembles the perspective of Social Network Analysis, which claims, in Wasserman and Faust’s (1994: 3) definition, that “the social environment can be expressed as patterns and regularities in relationships among interactive units. We will refer to the presence of regular patterns in relationship as *structure*” Therefore, from a theoretical macro-perspective, Field Theory and SNA share the same view of a social phenomenon, whose characteristics are bonded into the systemic pattern of relations that structure the possibilities and constrains of the agents.

Many network scholars have privileged the influence of structure among agents. From this perspective an actor is never free to act independently from his/her position within the structure, or to manipulate it in order to achieve his/her goals. But much work has been done to show that agents can take advantage from their position and use their strategic relationships to manipulate other agents in the network. Burt’s theory of structural holes (1992). for example, suggests that being able to control the information flow within a set of non-connected agents grants power and control over them. Also, Simmel’s (1983) work on triads has pointed to these advantages in earlier times. Therefore Social Network Analysis does not seem to privilege a unique direction of influence (of structure over agents). but assumes an interdependence between the structure of positions in which actors are embedded and the power they gain to act upon the network.

We can find the same attention to the influence of actors over structure in Bourdieu’s Field Theory. Bourdieu avoids the risk of overestimating a one-way influence (of structure upon actors) using the concept of *habitus*. *Habitus* is the system of disposition linked to every specific position in a field. It is the generative principle of objectively classifiable practices and, at the same time, the system of classification of such practices (Bourdieu 1984). In this way *habitus* is a structuring structure, because it is in charge of the organization of practices and their perception (therefore it reflects the influence of agents over structure and positions). But it is also a structured structure, that is to say it is the solidified product of social trajectories. In such a view, there is no preferred way of influence: actors internalise their *habitus* since they were born and use its dispositions to obtain their position in the field. On the other hand, they cannot think of different ways of obtaining what they want (apart from the rare cases in which they act reflexively, when they happen to be aware of structural constraints and to change their behaviour accordingly) because they are constrained by the set of dispositions which a *habitus* makes available. The concept of reflexivity has been used by Bourdieu (2004b) to address the critics of determinism: in his words:

*Habitus* is not the fate that some people read into it. Being the product of history, it is an open system of dispositions that is constantly subjected to experiences, and therefore constantly affected by them in a way that either reinforces or modifies its structures [...] It is difficult to control the first inclination of *habitus*, but reflexive analysis, which teaches that we are the ones who endow the situation with part of the potency it has over us, allows us to alter our perception of the situation and thereby our reaction to it” (Bourdieu 2004b: 133 - 136).

But just few pages before, the author himself specifies that:

here is a probability, inscribed in the social destiny associated with definite social conditions, that experiences will confirm *habitus*, because most people are statistically bound to encounter circumstances that tend to agree with those that originally fashioned their *habitus*. (Bourdieu 2004b: 133).

Social Network Analysis and Field Theory have some similar methodological implications. Both theoretical approaches are systemic, which means that every modification of a part of the structure (every change in relationships) has a variable effect on the whole structure. Some might be minimal, such as if we delete a peripheral pair of actors; others might be dramatic, for example if we delete cut-points or bridges. Such changes will then modify the whole network in terms of centrality scores, number of components and the like. Similarly, positions in a field might be equivalent in terms of the composition of symbolic capital that defines them, but social trajectories are singular and depend heavily upon the different experiences of actors. Therefore, both SNA and Field Theory suffer from data limitations which any inquiry might have to face, as both need to obtain data for more or less the whole population under investigation.

Another similarity lies in the fact that the boundaries of networks and fields are emergent properties that cannot be determined prior to the data collection. Social network research uses a wide range of methods to reach the population of a network, including snowball sampling (Bernard et al. 1989 and 1991), ethnographic observations (Johnson 1990) and perceived networks (Krackhardt 1987 and 1990). Boundaries can be defined by researchers, but they are artificial constructions that can be invalidated once data collection has commenced. Likewise, the boundaries of a field are situated where the field forces do not act anymore and agents do not fight for the same stake. They do not share the same *illusio*, “a specific form of interest [called forth by each field] as tacit recognition of the value of the stakes of the game and as practical mastery of its rules” (Bourdieu 2004b: 117). Identifying these forces and where they do not act anymore cannot be determined before the investigation of the field; it is a constructive process that happens during empirical research.

#### 4. The field of particle physics: sample and methodologies

The main difference between Bourdieu’s and SNA approaches is that SNA studies try to map and measure concrete relationships (citations, co-authorships, participations to events, informal collaborations), then abstract the objective structure of relationships via network analysis. Bourdieu instead makes uses of correspondence analysis, where relations between positions are conceptualized as deviations between results observed and results expected through random distribution “visually represented in factorial planes which weight them according to their distance from  $\chi^2$ ” (Bourdieu 1988: 69). It is interesting to note that SNA itself makes uses of comparison between values in empirical networks and values generated from random networks.

Bourdieu claims that “to think in terms of field is thinking relationally [...] what exist in the social world are relations – not interactions between agents or intersubjective ties between individuals, but objective relationships” (Bourdieu 1988: 96–97). Therefore, his concept of relation is reduced to the internal correlations between independent variables, leaving aside the concrete space of personal interchange. But while objective relationships are undoubtedly important, the everyday world of interactions (captured by SNA techniques) their meaning for the agents (obtained via qualitative interviews) are equally part of the social world, and cannot be overrated. We thus decided to follow Bourdieu’s methodological indications in our research project combining it with a Social Network Analysis perspective, to give an account of concrete relationships. Data collection has been conducted in several phases and with different techniques.

First of all we explored, via desk research, the organization of particle physics in terms of institutions involved, conferences, journals, and perceived boundaries. High Energy Physics (HEP) is a form of big science (Price 1963), and gains its scientific credit from a transnational field of research. There are three main laboratories (in California, Chicago, Genève), plus another dozen smaller laboratories distributed around the world. Publications are concentrated in American journals (*Physical Review D*, *Physical Review Letters*) and in less prestigious European journals (*Physics Letters*, *European Physics Journal C*). These constitute the main source of peer validation of knowledge production. While scientific prestige is gained at an international level, funding sources and professional positions are controlled at a national level, thus an Italian particle physicist has to fight against his or her national peers to obtain a job, career advancement, or research funding. Therefore, given the fact it was quite unrealistic to collect data on the worldwide field of HEP, we focused on the Italian scene. Italian particle physics is dominated by INFN (National Institute of Nuclear Physics) which is an independent institute with its own employees, four national laboratories, and 19 Divisions located within university physics departments, the latter being the other institutional loci of activities. Therefore INFN works closely related to universities, and research groups are normally composed both by INFN researchers and academic staff. Through desk research we gained information on



these institutions and their histories from websites, celebrative materials, and historical reports, in order to reconstruct the public self-account of the field.

Second, we identified the scientists who work on HEP in Italy. This operation was not as trivial as it seems, mainly because there is not a single institutional discipline called HEP in Italy. The Italian Ministry of University and Research (MIUR) divide the disciplines of physics into distinct areas: experimental physics, theoretical physics, material physics, nuclear and sub-nuclear physics, astrophysics, earth physics, applied physics and history and didacticism of physics. This means that a HEP researcher can be part of any of these branches according to his or her area of research (theoretical, experimental, etc.). together with other physicists who work on topics other than HEP (like nuclear theorists or astrophysicists). INFN is organised in Scientific Commissions, on particles, astro-particles, nuclear, theory and technological research. Given the fact that INFN was born specifically dedicated to HEP, we can assume that all the researchers there should be counted as part of the HEP field, even if some of them might also have interests that breach interdisciplinary boundaries.

We obtained access to the list of MIUR employees (professors and researchers) for all the areas of physics easily, as they are listed in MIUR website, likewise the INFN phone book, from the institution's website. Thus, we had to handle two different lists of names, both of which were neither exclusive nor exhaustive. The list of physicists working at universities from MIUR also contained the names of other kinds of physicists, and most of the HEP physicists collaborating with INFN. Therefore we had too many names in the MIUR list, and an overlap of these names in the INFN list. The INFN list also contained administrative staff and technicians, whom we needed to exclude from the list. We also found a list of Italian physicists in SPIRES (<http://www.slac.stanford.edu/spires/>). an international database that collects all the worldwide publications in the HEP field. This list is auto-compiled; therefore there is much missing data especially regarding the particular area of physics in which the people worked, but at least it contained all the names of Italians who published on a HEP related topic (dead or alive...).

We then compared these three lists of names. According to the number of publications in SPIRES, we deleted all the people in the MIUR list who have less than five articles on HEP (The threshold is been set according to the fact that some authors might have co-published a couple of articles on particle physics, even if HEP is not their main area of research). In this way we eliminated all the physicists who work on other topics. We then deleted all the names in the INFN list with no articles in SPIRES (The lower threshold is because of the fact that INFN list also contains postdoctoral students, who might have very few publications (administrative and technicians do not have publications, so they were excluded by the threshold). Finally, we compared the MIUR and INFN lists together to get rid of duplicates (given to the fact academic staff collaborate with INFN and are listed in its phonebook). We thus ended with a list of 4013 names. This number is consistent with aggregate data on INFN employees and academic collaborators we obtained from INFN itself. These first two phases of research allowed us to establish temporary field boundaries and provided the list of people and institutions about whom and which we needed to obtain information. This operation is inevitably arbitrary, as we already pointed out that the HEP field cannot be reduced to a national context. However, the several sources of data collection provided a general view of the internationalization of the discipline, allowing to place the selected representation of the field within a wider background where relationships with foreign institutions (particularly the European and American big experimental laboratories) were named.

While we pursued the desk research, trying to find as much information as possible on the people we listed, we also submitted an on-line survey to the 4013 physicists, asking them about their age, gender, place of birth, their family (father and mother's education and job). their education (institution of degree and PhD, names of supervisors). their job position (when and where they have been appointed). their participation to experiments, their administrative position (if they had held any important positions such as Deans, Heads of School, Vice-Chancellors and the like). their participation in national and international conferences, their contacts with media (if they had ever participated in radio, television and newspaper interviews or programmes) and their political affiliations (if they have ever been listed or elected for a political party, if they belong to any association). Finally, we asked them to give us three names of people who have been important for their career and three names of people with whom they mostly discuss their scientific results, and the reasons why they are important. We had 1015 respondents to our questionnaire (25% of the population). They cannot be considered representative, but for those who answered we collected information on biographical trajectories, composition of capitals, position within the field, and relationship with the dominant fields.

Moreover, we conduct 33 in-depth, unstructured interviews of physicists at different stages in their careers, as well as from different scientific areas (theory, experiment, astro-particle) and from different institutions (MIUR\INFN). We decided to adopt a mixed method strategy as we could not obtain exhaustive data on the whole population using only one method. In this way we collected diverse and complementary information on the field, which whilst not representative, nonetheless offers a consistent view of the shape and the dynamics of the Italian scientific community of HEP.

## 5. Multiple networks, one field

In order to reconstruct the structure of positions in the field, we collected data on economic, cultural and social capital of each of the particle physicists in Italy. For the economic capital, we could not obtain data from INFN, therefore we lack information on the main source of funding for experiments. The only indicator we have therefore is the number of experiments in which every INFN division participates, and from which we extract the network of divisions' collaborations in experiments. We did however collect data about the MIUR funding (only to universities) of physics PRIN from 2000 to 2006 (available from MIUR website). For every funded project, we acquired detailed information on the amount of funding every research unit received and the names of national and local coordinators, together with institutional affiliations. These funding arrangements, according to qualitative accounts, are strategic in the field as they provide money to open temporary positions for postdoctoral scholarships (for young physicists) which are very rarely funded by INFN. Moreover, they can be obtained only by academic staff, which means that Universities control the majority of the accesses to the field, in terms of tenure track positions. Using these data we locate the field of HEP against other physics disciplines, and see which percentage of funding has been direct to HEP over the total amount of funding for physics (We collected data on the whole field of physics, therefore there are research projects related to other disciplines in the field.). Moreover, after eliminating the names of people who do not appear in our 4013 name list, we extract the network of collaborations to research projects between physicists and between institutions, using the amount of funding as an attribute of nodes. We also use the number of people working at universities and INFN divisions as a rough indicator of the economic capital of each institution, as it indicates the salary expenses they have to afford. Therefore, for economic capital we are able to produce reliable maps both for individuals and institutions.

As indicators of cultural capital (Bourdieu, 1986). we use data from the on-line survey. We distinguish between:

- Embodied cultural capital, where we consider the level of educations of parents as an indicator of family cultural capital.
- Institutionalized cultural capital, where we consider the age at time of graduation, the possession of a PhD, and the institutions of degree and PhD (especially where they are the same, which happens in 59.7% of cases). This is then aggregated for each institution.
- Objectified cultural capital. Normally, this indicator consists in the number of publications, but in experimental particle physics articles are signed by the whole collaboration, making it difficult to attribute a specific amount of capital to every actor in the field. Qualitative accounts suggest different strategies to attribute cultural capital, like participations at conferences (where who presents is the main author of the paper).

Finally, indicators of social capital are networks of collaborations to PRIN projects (from desk research). of collaborations to experiment (from on-line survey). and egonetworks obtained from questions about important people (from on-line survey). Egonetworks have been combined together to form a whole network of personal relationships. While suffering from the lack of data (they represent only 25% of the population and not everyone who answered the survey had answered the network questions section). this network is useful to identify some of the most influential people in the field.

The SPIRES database also offers a wide range of information useful to attribute symbolic capital. It indicates Nobel Prize winners, for example, which are the most important sign of recognition in the field. It provides names of PhD thesis supervisors, which can be used as a source of social capital. However, the database suffers from a large number of missing data; therefore desk research is used to compliment this, albeit limited by seems to be the most appropriate way to implement data about people it's nature as time consuming and highly incomplete, as data sources (like departments and experiments websites, institutions archives, on line CV) are not uniform and are not regularly updated.

Data collected have been interpreted using qualitative accounts. The physicists explained to us the strategies of affiliation they need in order to establish research groups and to advance in their careers. From this we are able to go beyond the formal relationship of collaboration that emerge from quantitative data and discover that it can happen that institutional collaboration (like participating to the same experiment) might hide some internal contrasts regarding scientific decisions, responsibilities, control over job opportunities, personal friction, contrasting ambitions, and the like. Social trajectories of Italian physicists have been reconstructed using survey data, while the relationship with dominant field (politics, media, industry) and controversies over the criteria of validation of knowledge production have been explored using both survey data and qualitative interviews (Bellotti, Beltrame and Volontè 2008).

## 6. Preliminary findings and discussion

While data analysis has still to be completed (preliminary results can be found in Bellotti, Beltrame and Volontè 2008), some consideration over methodological choices can be addressed. Field Theory is a good approach to show the social elements that shape the production of knowledge: it takes into account the role of structure on agents as well as the power of agents in manipulating ties and modifying the structure. Compared to SNA, Field Theory seems to have a wider perspective, as it aims to collect much more information on the overall composition of capitals that constitutes positions in the field. Therefore we privileged Bourdieu's theoretical perspective in an attempt to provide a reliable picture of the production of knowledge in particle physics. But unlike Bourdieu, we do not use correspondence analysis mainly because of the lack of exhaustive data. However, Social Network Analysis techniques are equally useful to represent the shape of the field, as they map concrete relationships between individuals, and via transformation of affiliation matrices, between institutions. Representing the structure of the capitals' disposition via SNA we do not attribute specific symbolic value to individuals (in terms of their own weight compared to everyone else's), but we observe how such value is obtained by physicists using the combination of capitals his or her position entails.

The network of collaborations to PRIN projects, for example, represent how people obtain economic capital (funding) using their cultural capital (their scientific value in term of publications, experimental experiences, and legitimate titles) to make ties with other scientists and develop collaborations (social capital), in order to achieve results and gain scientific prestige. Such interpretation comes from the qualitative accounts, where physicists explain how people construct and develop PRIN collaborations:

If we look at the research groups that are granted by PRIN, we can see that they are normally lead by very experienced people, the older ones, the ones with more credibility. They are the most acknowledged. MUA65 (Interview codes indicate gender, institution, academic position, year of birth).

In PRIN projects we offer our technique; we are experts in this technique that uses neutrons, x rays, synchrotron's radiations. Therefore in a PRIN project we are normally involved for our technique that we adapt to the project's needs. MUR61

I managed to create two postdoctoral scholarships from two PRIN projects, and I used one of them to offer a position to a Russian colleague. He was already here at my University working with another group; therefore we had already started to work together as I occasionally had contacts with the senior researcher in his group. MUA64

We then use these accounts to interpret the network data. The valued adjacency matrix we obtain from the affiliation of people to projects contains the number of projects people share in common, which varies from 0 to 6. Progressive visualization of the increasing strength of ties reveals cliques of people who tend to often work together, and belong to different institutions (see Figure 1). We can correlate this value with the amount of obtained funding, the institution affiliation, the role in the academia, the gender, and other attributes; given the fact we collected longitudinal data (from 2000 to 2006), we can also see variations in the clique structure over years. This is just an example on how these data can be combined via Social Network Analysis, and can be interpreted from an



internal point of view, where the physicists interviewed explain the dynamic of power, alliances, conflicts and exchange they strategically use to develop research projects and obtain funding.

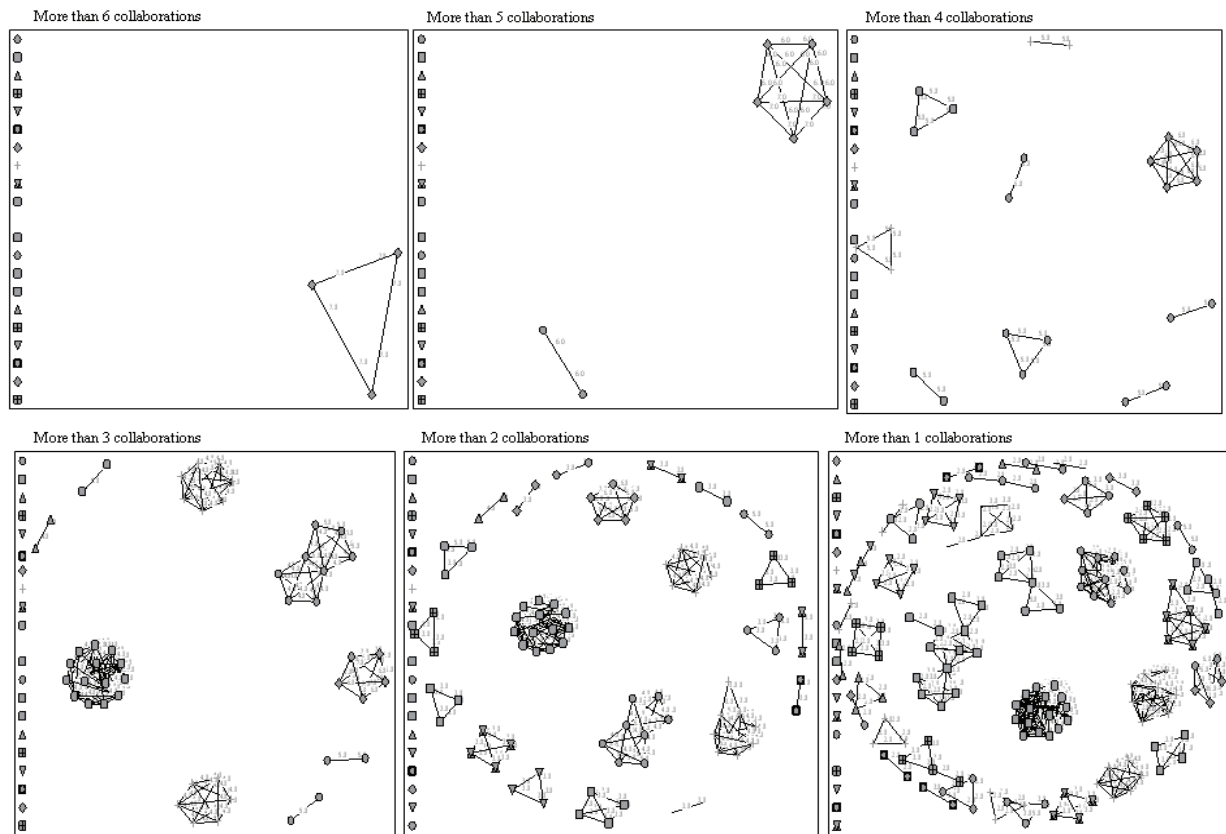


Figure 1: number of collaborations to PRIN projects between physicists (aggregate values for the 6 years, the shape of nodes indicates components affiliation).

We can now go back to the comparison between Bourdieu's Field Theory and SNA perspective and draw some conclusions. Bourdieu's Field Theory consist of relations of distance and proximity between positions: these relations are intended in terms of statistical divergences and convergences of observed values from expected values, and are internally related to each other in a factorial plane. In this way Bourdieu manages to represent the structure of the field using the internal forces that shape the symbolic space of positions, as these positions are defined by the composition of indicators of the different amounts of capitals that have been counted for every actor. The strength of this approach is that it does indeed represent structural relations which do not depend on the local and contextual system of relationships between people; this can be highly variable, as it depends on contingent factors that shape everyday context of exchange. With his theoretical approach, Bourdieu seems to achieve the goal of mapping structural opportunities and constraints which are independent from the stream of events that happen by chance. But as Gilbert and Mulkay have shown (1984), casual and incidental events (informally accounted using a contingent repertoire) are important as they reveal the rhetorical work that scientists make in order to hide themselves under the "empiric repertoire", the formal language of scientific papers, and therefore testify to the sharing of the *illusio* in the field.

SNA represents a different perspective, where relations are concrete interactions between actors; SNA measures still make it possible to account for structural possibilities every actor in a field has to hand. Moreover, if we observe them over time, we are able to find structural features that tend to remain constant or vary across the years. Therefore we can explore the objective relations between positions even by starting from concrete exchanges

between people. They can be combined with qualitative methods that are useful to understand these dynamics and rhetoric from the internal point of view of scientists who belong to the field. They provide a meaningful account of the value of the relationships in which physicists are involved, and allow contextualising the otherwise abstract structural shape that comes out from both Bourdieu's and SNA's approaches.

These theoretical standings and their correlated methods do not seem to be in conflict: they are complementary, as they explore structural features from different perspective. But Bourdieu, in his attempt to search for the "trans-historical inter-variants, or sets of relations between structures that persist within a clearly circumscribed but relatively long historical period" (Bourdieu 2004b: 78) seems to leave aside the concrete events that happen in the real world, where physicists interact everyday and which are the focus of most of the contemporary sociology of science. SNA perspective instead is capable to take into account concrete relationships, and abstract from them the structural features that shape the field.

## 7. Conclusions

In this paper we presented the theoretical background and the methodological choices of a PRIN research project on the production of knowledge in particle physics in Italy. We revised the current state of sociology of science literature, presented Bourdieu's Field Theory, which has been the main theoretical perspective of our project, searched for possible similarities, differences and complementarities between Bourdieu's approach and SNA techniques, and explained how we proceeded to select the population and collect data.

Data collection has been a long and difficult task, and we did not manage to obtain all the information we were looking for, mainly because of lack of time and funding, but also because these data are most of the times incomplete or inaccessible. We then decided to opt for a mixed method strategy to overcome the problem of lack of information. Gathering data through multiple methodologies has proved to be an effective strategy for reconstructing the field of particle physics in a consistent way. In particular, SNA techniques have been extremely useful to represent structural features we could not observe via correspondence analysis. But SNA techniques have also proved to be closer to the reality of physicists' experience, as they look for concrete relationships and abstract the structural disposition of the field starting from contextual interactions.

More work has to be done both on the side of data collection and data analysis. Network structures have not been fully analyzed yet; therefore we cannot provide a complete representation of the field. Also, we still need to gather data on scientists' publications, in order to correlate the effective production of knowledge in particle physics with the structural dispositions, possibilities and constraints of the field. These last tasks we hope will constitute material for the next article.

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